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A simple device for determining the deep drainage in soils

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Tube Tensiometer Installation and Operation Guide

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CSIRO Land and Water
Technical Report 12-02, April 2002

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Introduction

The **Tube Tensiometer Installation and Operation Guide** provides information on how to install and operate the Mk3 Tube Tensiometer.

What is a tube tensiometer ?

The Mk3 Tube Tensiometer is a specialized tensiometer for measuring the soil water potential (ψ) in the range 0 to –100 cm of water. For many soils this range is where the soil is close to saturation and is rapidly draining.

The Tube Tensiometer (TT) has advantages over many other tensiometers. It can be deployed long term without requiring routine maintenance, it does not protrude into the cultivated zone and it has the resolution and accuracy required for estimating the vertical drainage flux q from Darcy's Law;

$$q = K(\psi)\,(1 - \partial\psi/\partial z) \qquad [1].$$

To estimate vertical drainage flux, two TTs are installed at one site and the soil water potential gradient ($1 - \partial\psi/\partial z$) is estimated. The TTs should be vertically separated by 20-50 cm, be within a layer of soil that has uniform hydraulic properties and be horizontally spaced as close as practical. The hydraulic conductivity $K(\psi)$ of the layer is obtained from other measurements such as pedotransfer functions (Schaap *et al.* 2001), in-situ measurements with disc permeammeters (Perroux and White, 1988) or by taking soil cores and processing these through a soil hydraulics laboratory (McKenzie and Jacquier, 1996; McKenzie et al. 2001)

Figure 1 shows a schematic of the TT. The instrument consists of a 100 cm long open-topped tube (2) filled with diatomaceous earth (1). At the base of the tube is a cavity (5) that is separated from the diatomaceous earth by a fine mesh screen (4). This cavity is connected to the surface via a vent tube (6). At the base of the cavity is a pressure sensor (7) that returns an electrical signal to the surface via a cable. The sensor enclosure (8) is connected to the surface via a dry vent tube or vented cable.

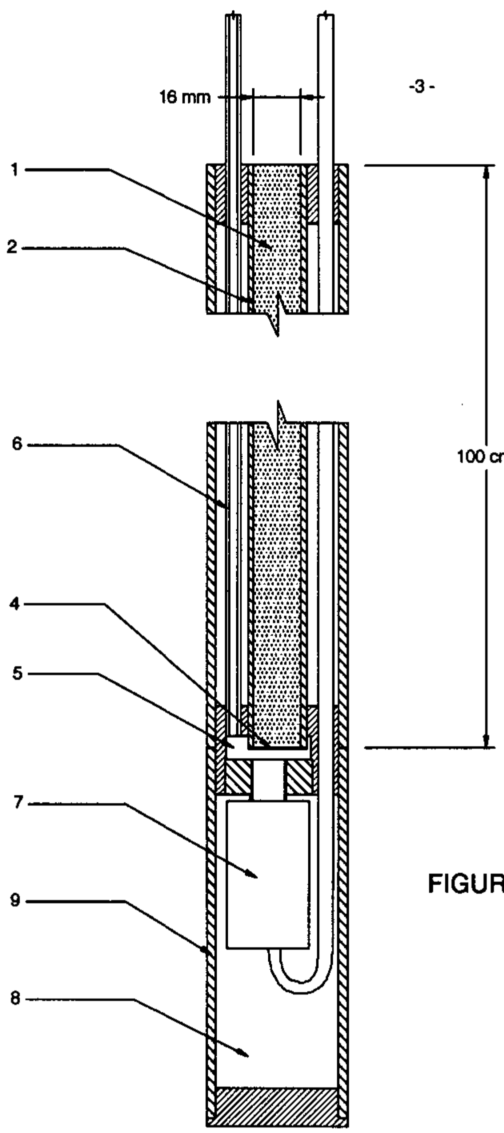

FIGURE 1

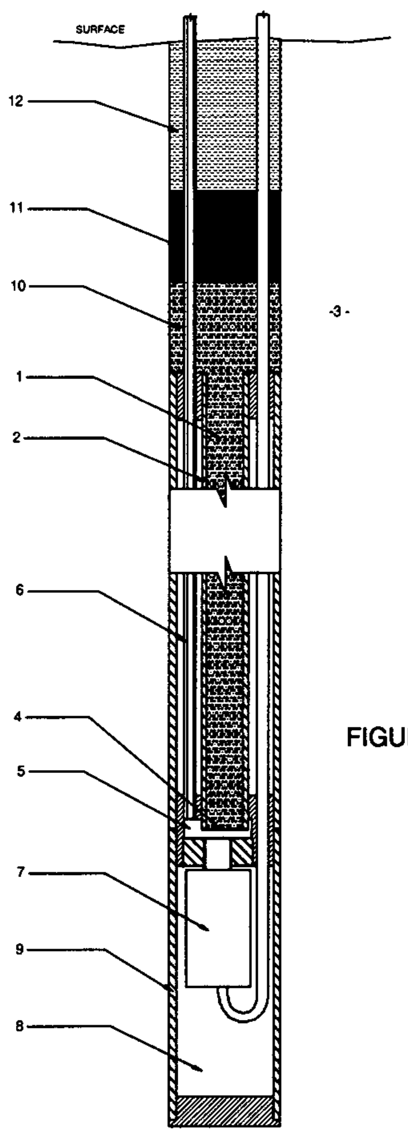

FIGURE 2

Figures 1& 2 Schematic of TT internal components (left) and installation (right)

The TT is installed by augering a hole approximately 1.2 m beyond the depth of interest and lowering the TT to the bottom (Fig. 2). A sensing tip (10) is then fashioned by packing 5 cm of diatomaceous earth on top of the tube and against the sides of the augured hole. The hole that remains above the tip is then partially filled with bentonite clay (11) to prevent moisture travelling through disturbed soil and, finally, native soil (12).

How does it measure tension?

As with traditional tensiometers, water will move in/out of the column depending on the potential difference between the soil and instrument. This moisture distributes throughout the column until equilibrium is achieved between the force of gravity pulling the moisture to the bottom of the tube, and capillary action pulling the moisture back out of the tube. At equilibrium, the soil water potential in the tube is linearly distributed with depth, with the diatomaceous earth wetter at depth and drier at the tip. If the soil water potential adjacent to the tip is wetter than –100 cm of water then, at equilibrium, a water table is formed in the tube and the soil water potential at the tip is given by the TT as

$$\psi = p - L \qquad [2]$$

where p is the fluid pressure (in cm of water) measured at the bottom of the tube and L is the length of the tube plus half the height of the sensing tip (Hutchinson and Bond, 2001)

Part 1 – Preparation

Checking Tube Tensiometers (at delivery)

The TTs have been delivered to you in a sturdy box that should prevent any damage in transit. However, check the instruments during unpacking for signs of damage to the casing, cables or vent tubes. Evidence of impacts to the instruments or extreme damage to the box suggests the instrument has experienced high impact. If so, their calibration should be checked and they may require full re-calibration.

Materials and tools required for installation

Item	Comments, suppliers and costs
200g of diatomaceous earth per TT	Local swimming pool shop, used in swimming pool and water filters. Bags are $20 for 4 kg.
2 kg of granulated bentonite per TT	Rural stock feed supplier, used in stock feed. Bags are $9 for 40 kg.
Packing rod, 17 mm diameter, 1.2 m long.	A length of wooden dowel from the hardware store will be suitable.
Packing rod having a ϕ30 mm end and length to suit depth of interest plus 1.5 m.	A length of 1" wooden dowel with a PVC chair tip over one end from the hardware store will be suitable.
3/16" OD nylon semi-rigid pneumatic tubing, length to suit application.	Standard tubes from the TT are 4 m long. These may need extending to the logger. Tubing available from engineering supplier. Esdan E100-03 or similar.
100 mm of 3/8" OD x 5/32" ID vacuum hose. Two required per TT if vent tubes	Tubing available from engineering supplier.

are extended.	
2-pair data cable (7×0.2 mm each conductor) with PVC sheath, length to suit application.	Standard cable is 4 m long. These may need extending to the logger. Cable available from electrical supplier. Electra EAS7202P or similar.
4 × 2-wire gell-filled splice terminals per TT required if cables are extended.	For connecting data cable. Available from electrical suppliers. Scotchlok UY2, Utilux H42111 or similar

Augers suitable for making a 52 mm hole to the required depth (see later)	Hand augers suitable for sand and clay are available from Dormer Engineering, Murwillumbah NSW ph. 02-6672-1533.
Roll of adhesive 5 cm wide plastic tape	Duct tape or packing tape from hardware store.
Small funnel and teaspoon	The top of a small plastic soft drink bottle makes an ideal funnel because it has a wide throat to suit the DE column tube.
2 Steel or wooden pegs 50 cm long	Shortened star pickets are ideal.
Builders level	~80 cm long
Tape measure	5 m & 25 m
Bricklayers hammer	
Potting trowel	
Measuring cups	100/200/400 mL (1 each)
Cable ties	100/200/400 mm (various)
Silicon rubber sealant, neutral cure.	Silastic 747 (50 mL per TT)
Plastic pipe for potting of cable joint	25 mm dia x 150 mm (1 per TT pair)
Retort clamps and hardware for holding tube while packing with DE	2 required.

Table 1. Material required for installation of TT

Preparation of internal diatomaceous earth

Caution: Handle diatomaceous earth with care. Long term exposure to high dust concentration may cause changes in lung function (see Chemwatch Material Safety Data Sheet 21851)

Place 200g of dry diatomaceous earth (DE) per TT into a plastic bag. Add 300 ml of water and seal bag. Mix contents by shaking the bag and manipulating the contents by hand through the bag. If the DE has the correct water content for packing then a handful of DE forms a fragile bolus when squeezed firmly and will just about express a drop of water at the same time. This mixture will be used in the TT's internal column and its external sensing tip.

Packing of diatomaceous earth column

Brace the TT upright from a convenient solid object with its base resting on firm ground (Fig.3).

Figure 3. TT clamped to utility body (left) in preparation for packing of DE (right)

Place about 10ml (a heaped teaspoon) of DE into the TT using a small funnel and a teaspoon. Lower the smaller diameter packing rod onto the DE and pack firmly. Do not drop the packing rod onto the DE, or use a force exceeding 1kg (Fig. 3). Repeat process until tube is filled to the top. Place adhesive PVC tape, about 50mm wide, across top of tensiometer to prevent loss of moisture from DE prior to installation.

Part 2 - Site selection

Soil layering

Ensure site is representative of surrounding area. This may require a soil coring survey.

If pairs of TTs are to be installed for measuring the soil water potential gradient and for estimating the moisture flux using Darcy's Law, then it is important that they are installed in a layer of soil that has uniform hydraulic properties. Generally, a layer having uniform hydraulic properties can be found in the soil profile, but it may not always be at the depth where moisture flux measurements are required. In this case the TT's may have to be buried deeper where the hydraulic properties are uniform.

The TTs should be horizontally spaced as close as is practical (20-30 cm).

Establishing the site

Identify the site and limit vehicle and foot traffic to a minimum. If necessary, use planks supported at their ends to minimize compaction immediately above and near the instruments during installation, especially if the soil is wet.

Locate a position for the logging equipment. Instrument cable and vent tube tails are 4 m long and will require lengthening to suit the particular configuration. Vent tubes should have a slight positive gradient at all points over the run to the logger. This will prevent condensation from being trapped in the tube. Other considerations include solar panel and antenna orientation and any rain shadow that these structures may have on the measurement site.

To provide a datum for surveying the depth of the TTs, hammer in two pegs 50 cm apart and ~30 cm above the ground to span the measurement site. Adjust the pegs so the tops are level (Fig. 4)


Figure 4. Establishment of the datum for surveying in the depth of the TTs.

Depth calculations

To estimate the drainage flux from Darcy's Law (Eq. 1) two TTs are installed at the same location but at two different depths z_1 and z_2 and Darcy's law is approximated using

$$q = K(\overline{\psi})\left[1 - \frac{\psi_1 - \psi_2}{z_1 - z_2}\right] \qquad [3]$$

where ψ_1 *and* ψ_2 are the soil matrix potentials measured at these two depths and $\overline{\psi} = (\psi_1 + \psi_2)/2$ is the average soil water potential at the mid-point $(z_1 + z_2)/2$
This mid-point is the *depth-of-interest* which is the depth from the mean soil surface to the centre of the DE sensing tips.

To determine the target depths of each hole (Fig. 5) from the datum use the following steps:

1. Measure and record the height of the datum above soil level (Fig. 4).
2. Determine the depth-of-interest *DoI* and vertical separation *S* between the TTs by considering the root-zone extent and soil layering.
3. Calculate the depth to the bottom of the holes from the datum using

$$D_1[cm] = DoI + D + 113 - S/2$$
$$D_2[cm] = DoI + D + 113 + S/2$$

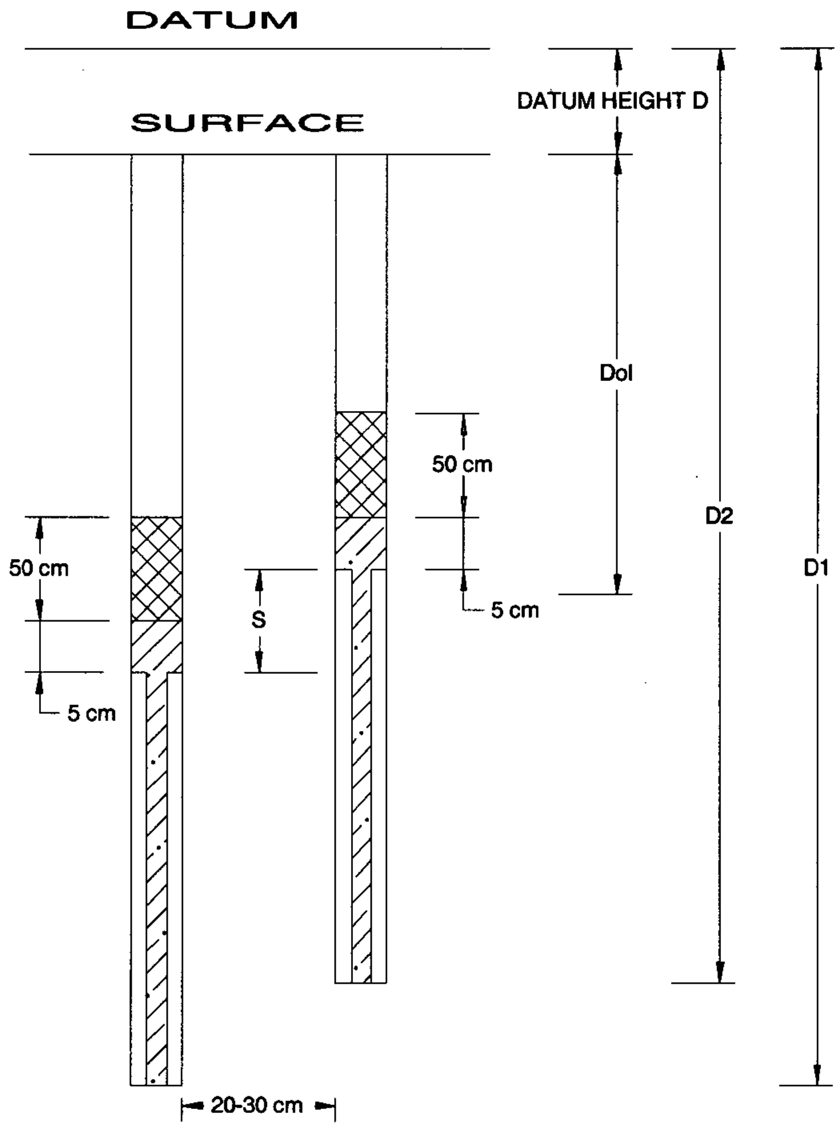

Figure 5. Relationship of the pair of tube tensiometers to the depth-of-interest.

Part 3 - Installation of tube tensiometer

Augering or coring holes

Auger or core the hole to D_1 and D_2 from datum (Fig. 6). Use PVC tape around the auger or corer shaft to mark target depth. Separate soils from the top of the profile for use as final back-fill. Clean out the hole and check its depth.

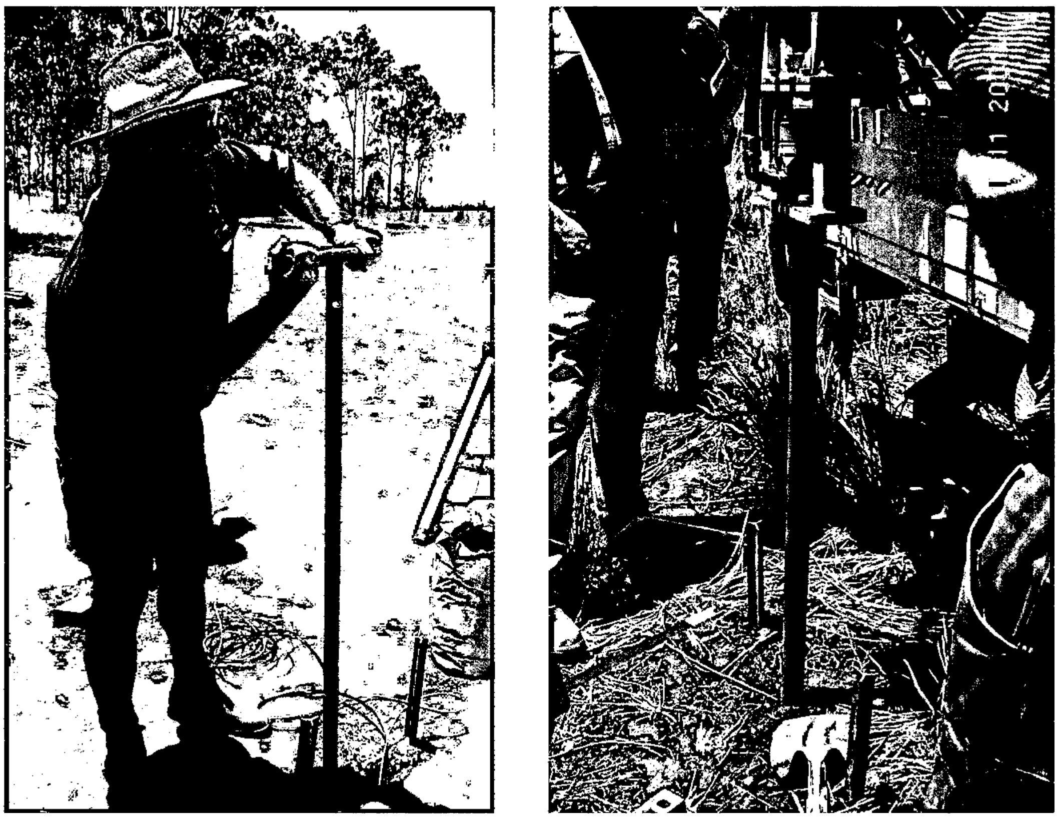

Figure 6. Mike Bell augering a hole at Glenburn, QLD in red brown earth (right) and use of the hydraulic push tubes to prepare holes at Dalby, QLD (left).

Check to ensure that the sides of the hole that will be in contact with the DE sensing tip have not been sealed or smeared by auger or corer action. If necessary, use a large bottlebrush or similar to remove smearing at the location where the tip will be formed.

If the hole is more than 53 mm diameter then the top of the TT should be wound with plastic tape to increase the external diameter to suit the hole. There should be a clearance between the hole and the tensiometer of 2-3 mm.

Lowering TT

Lower TT (internal DE column pre-packed) into place to the bottom of hole. This is best achieved by maintaining tension on the TT tails against the clean end of the larger diameter packing rod (Fig. 7). Bed-in the TT by applying firm pressure via the rod. Satisfactory bedding is necessary to prevent the TT later dropping and losing hydraulic continuity with its sensing tip. Check cleanliness of the top surface of the TT body, in particular the top of its DE column. If necessary, wipe or sponge it clean so that there will be an uncontaminated hydraulic connection between the DE of TT column and the sensing tip

Figure 7. Lowering the tube tensiometer to the bottom of the hole while holding the cables taut.

Surveying the TT

Measure the depth of the top of the TT from the datum to an accuracy of ±2 mm using a tape measure (Fig. 8)

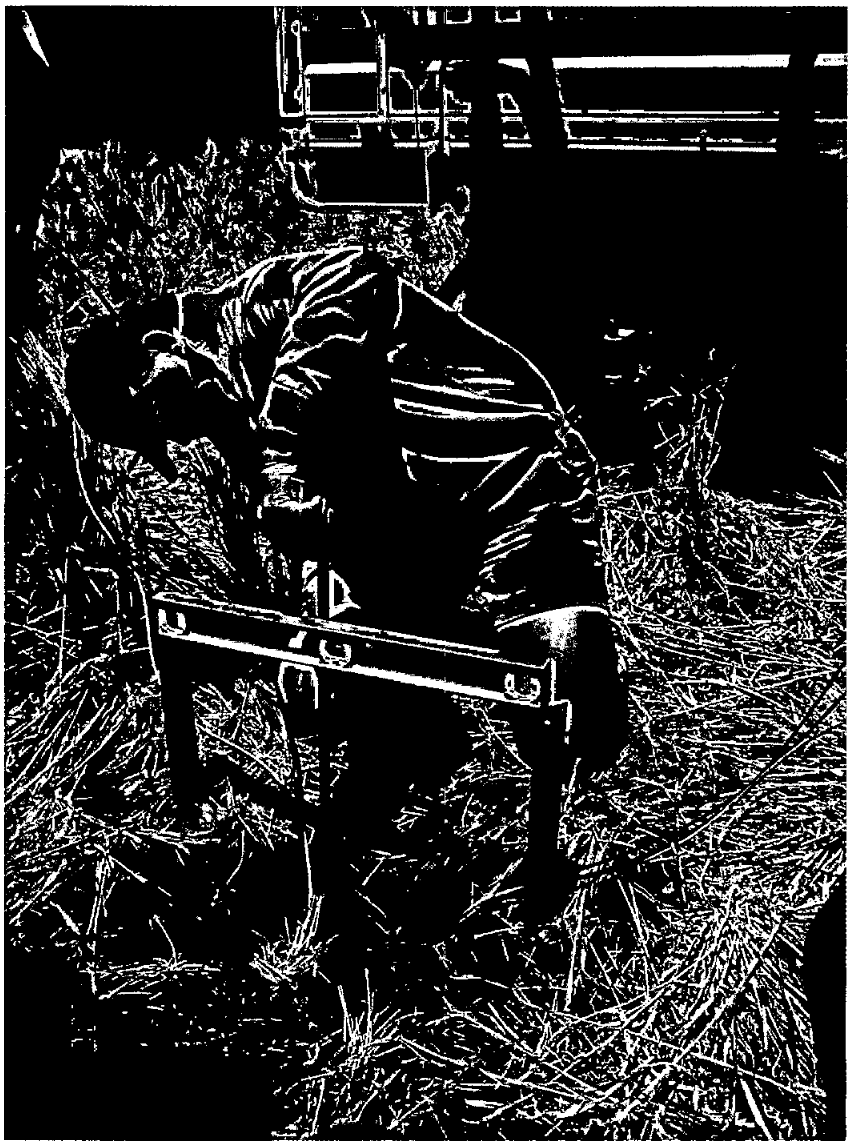

Figure 8. Surveying the depth of the top of the TT

Packing the tip and seal

Maintain slight tension on the TT tails so that they remain vertical in the hole and minimize dislodgement of material from the sides. Tip a small quantity of moist DE (75 ml) into the hole and pack it firmly against the top of the TT and the side walls of the hole using the larger diameter packing rod (Fig. 9). Continue to add quantities of DE until the tip is 5 cm high (Fig. 5). Measure and record the actual height of the tip.

After the DE tip is in place slowly pour granulated bentonite into the hole, ramming the granules with a narrow packing rod. The height of the bentonite seal should be greater than 10 cm, but do not bring bentonite to within 50 cm of the surface. Repeat for the remainder of the hole to the surface using native soil previously obtained from the same part of the profile.

Figure 9. Packing the DE tip.

Cables and tubes

Cables and vent tubes are run below the cultivated zone in a back-filled trench (Fig. 10)

Figure 10. Trench dug to bury cables and tubes.

Tube tails are 4 m long allowing joints to be placed 2 to 3 m from the instruments. Individual cable conductors can be joined using self-sealing crimp wire connectors. Strip about 50 mm of outer sheath from each cable and trim all material other than the four wires. The shield is not required for the last few metres of the cable run to the instrument. Maintain the pairing of the wires by applying a few twists as they exit the sheath. Follow the manufacturer instructions for use of the crimp connectors. Joined cables should be bound about their outer sheathes with a cable tie to minimize stress on seals and electrical connections (Fig. 11).

Figure 11. Wires joined with crimp connectors and tubes connected with vacuum hose.

After joining the cables, transfer their identifiers to the logger end of the free tail. The completed joints could be further water proofed by inserting them in one end of a short length of PVC pipe (Table 1). Both ends of the pipe are then sealed using neutral-cure silicone rubber. One length of pipe can contain the joints for a pair of TTs.

To minimize the possibility of condensation being trapped in the vent tubes insure the tubes run uphill to the logger enclosure or wherever they are vented to atmosphere.

The open ends of all vent tubes or their manifold should be plugged or covered with fibrous material to prevent the entry of insects or free water. Venting into the logger enclosure provides added security.

Part 4 – Logging

Outputs and wiring

The TT has two independent current loop outputs, each connected via a twisted pair of insulated wires. This configuration provides some immunity to problems associated with cable length variations and external noise pickup. They can be used to drive either a differential or carefully designed single ended logger input configuration. Please refer to your data logger manual to determine how to connect these current output devices Twisted pair colour coding and connection polarity is described in Table 2.

Wiring - twisted pair	Function	Colour	Connection
1	Pressure from SenSit M6420	Blue White	- [to current sensing resistor] + supply [10-30VDC]
2	Temperature from AD590	Orange White	- [to current sensing resistor] + supply [4-30VDC]

Table 2. Wiring configuration of the tube tensiometer

Note: both the pressure and temperature sensors can be damaged by reverse polarity, over-voltage or AC current.

The pressure signal is provided by an industry standard 4 to 20 mA DC two wire current loop. A minimum of 10 VDC should be available across the sensor for reliable operation. A minimum 12 VDC supply is recommended for the pressure sensor loop in conjunction with a maximum precision series resistor value of 249 Ohms. In that configuration, the range 4 to 7 mA will develop 1 to 1.75 V across the precision resistor and correspond approximately to –100 to 0 cm of soil water potential.

The temperature signal is also a non-zero DC current loop and requires a minimum of 4 V developed across the sensor. The sensor returns 1 uA K^{-1} and the range 270 to 300 uA corresponds approximately to 0 to 30 °C. The same 12 V source as the pressure sensor loop is appropriate. Less than 0.1 °C shift for each Volt of supply variation can be expected from the sensor if a lower voltage is used. A 5.9 kOhm series precision resistor will develop an approximate range of 1.6 to 1.8 V corresponding to 0 to 30 °C.

A two-point check of pressure sensor operation can be performed prior to the packing of its DE column. When the instrument is completely dry it should return approximately 4 mA current. If the instrument tube is completely filled with water and held vertical it should return approximately 7 mA. Exact values are influenced by temperature and can be determined using information contained in the calibration report (Appendix).

A check of temperature sensor operation can be performed at any time pre-burial.

Calculating the soil water potential

To calculate soil water potential ψ [cm] the first step is to calculate the sensor temperature T [^{o}C] from the sensor output I_T [mA] from the AD590 temperature sensor using Eq. 4

$$T[^oC] = c_T \times I_T - 273.2 + \Delta T \qquad [4]$$

where c_T and ΔT are constants supplied with the calibration sheet
The second step is to calculate corrected pressure sensor output I_{PT} [mA] from the pressure sensor output I_P [mA] using Eq. 5

$$I_{PT}[mA] = I_P + a_T(T - T_P) \qquad [5]$$

where a_T and T_p are constants supplied with the calibration sheet
The final step is to use Eq. 6 to obtain the soil water potential

$$\psi[mm] = a_P \times I_{PT} + b_P + h/2 \qquad [6]$$

where h is the height of the diatomaceous earth tip and b_p is a calibration constant.

If a data logger is used to store only raw output values then the standard deviation of temperature δT and the temperature corrected tension $\delta\psi$ can be calculated from the standard deviation of the temperature sensor output δI_T and the pressure sensor output δI_P using the following equation;

$$\delta\psi = a_P(\delta I_P + a_T \times c_T \times \delta I_T) \qquad [7]$$

A calibration report has been generated for each instrument (see Appendix)

Data resolution

To obtain an estimate of drainage flux to within ±25% and by considering the uncertainty in all the other input parameters to Darcy's (Eq. 3), the required accuracy of the tube tensiometer is ± 0.6 cm (Hutchinson and Bond, 2001). The logger resolution should be an order of magnitude greater i.e ±0.6 mm.

Loggers such as the Campbell CR21x, DataTaker DT500 or Unidata Prologger have sufficient channel resolution to achieve the required soil water potential. However, an 8-bit logger reading a 2.5 V channel with a hardware configuration similar to that described in section 4.1 above would not have the resolution required.

Sampling and averaging interval

The minimum sampling and averaging intervals of the logger will be influenced by the time scale of the drainage event, space available in the logger for data and the capacity of the power supply of the logging system. In dryland field trials using a Measurement Engineering Australia (MEA) system based on a Unidata ProLogger a 5W solar panel and a 7 Ah 12V sealed lead acid battery, a sampling interval of 15 minutes was feasible and adequate to record drainage.

The standard deviation should also be measured and recorded in order to troubleshoot problems such as sensor stability. The standard deviation of a working TT should be < 3 mm.

Part 5 – Trouble shooting

Symptom	Possible causes	Solution
TT does not respond to wetting	blocked vent tube	- remove blockage by applying <5 m suction to the vent tube - check that the vent line slopes up toward the logger
High value for soil water tension	break in pressure sensor current loop pressure sensor pair transposed with temperature sensor low or nil supply to pressure sensor current loop	- check all connections - check colour coding of cable pairs - ensure at least 10V across pressure sensor pair
Low value for soil water tension	leakage path across pressure sensor current loop	– check cable joints and logger connections
High value for temperature	leakage current path across temperature sensor pressure sensor pair transposed with temperature sensor	– check joints and logger connections for moisture and cleanliness – check colour coding of cable pairs
Low value for temperature	low or nil supply to temperature sensor current loop	– ensure at least 4V across temperature sensor pair
Diurnal variation in soil water potential values while maintaining realistic temperature variation	supply voltage dropping below 12V during night Water in venting tube causing air to	– check solar panel and battery capacity combination – re-lay vent tubes to avoid depressions

	expand/contract with temp	where water can be trapped in tube.

High standard deviation	logger resolution low insufficient warm-up/settling period prior to sampling	– logger input channel configuration – moisture on sensor connections

Appendices

Tube Tensiometer calibration report (extract)

Date : 20 Feb 2002
Issued to: Mark Silburn - QDNRM

Serial Number	a_p [cm mA^{-1}]	b_p [cm]	T_p [°C]	ΔT [°C]	a_T [mA °C^{-1}]	c_T [K mA^{-1}]
091	32.069	-233.05	21.22	-1.83	-0.0225	10^{-3}
092	31.821	-229.30	22.22	-0.83	-0.0033	10^{-3}
093	31.827	-229.23	21.87	-0.63	-0.0371	10^{-3}
094	32.677	-217.85	22.37	-1.13	-0.0340	10^{-3}

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